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14. ABSTRACT

This paper reviews the main threats to energy supply in order to determine their impact on security and military forces. It is divided into three sections. Part 1 provides some background to better understand the nature of energy transformations and highlights previous transformations and draws out some of the lessons that are relevant to the situation today. Part 2 provides context for understanding the threats to energy supply by reviewing the contemporary energy environment by briefly examining current general consumption patterns and reviewing the forecasted growth for the coming decades. It then reviews the concept that the oil age is ending and briefly explores the primary alternate energy sources under development today. Understanding the contemporary energy environment will allow readers to better appreciate the potential impacts from the threats to security that will be examined in the third section of this paper. In Part 3 examines contemporary threats to fuel supplies. These threats include interruptions whose origin may be human or environmental. Finally, the conclusions presented in Part 4 regard the potential impact of the condition of the energy environment as well as the threats to supplies both for countries and military forces.

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TTCP TECHNICAL REPORT

Energy Security Threats

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Peter Johnston

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CONTENTS

1. Introduction[1]

The world has experienced episodic disruptions to oil and gas supply in recent years that focussed attention on the issue of energy security. While interruptions are not a new phenomenon, their occurrence has garnered closer scrutiny due to concerns that increasing demand might outstrip the capacity of the markets and because of the understanding that fossil fuels will eventually decline to the point that they cannot be relied upon to fuel our economic, social, transportation, and military requirements. Another concern is the impact that energy use is having on the environment.

This paper reviews the main threats to energy supply in order to determine their impact on security and military forces. It is divided into three sections. Part 1 will provide some background to better understand the nature of energy transformations. It will highlight previous transformations and draw out some of the lessons that are relevant to the situation today. Part 2 will provide context for understanding the threats to energy supply by reviewing the contemporary energy environment. It will do so by briefly examining current general consumption patterns and review the forecasted growth for the coming decades. It will then review the concept that the oil age is ending and will briefly explore the primary alternate energy sources under development today. Understanding the contemporary energy environment will allow readers to better appreciate the potential impacts from the threats to security that will be examined in the third section of this paper. In Part 3 contemporary threats to fuel supply will be examined. These threats include interruptions whose origin may be human or environmental. Finally, conclusions will be reached in Part 4 regarding the potential impact of the condition of the energy environment as well as the threats to supplies both for countries and military forces.

2. Energy Transformations

Early Energy Usage

For most of recorded history, humans relied upon wood and carbohydrates to power their cooking, heating, work, and transportation needs. Beasts of burden

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[1] The reported results, their interpretation, and any opinions expressed herein, remain those of the author and do not represent, or otherwise reflect, any official position of the Department of National Defence or the Government of Canada.

were fed grasses or other naturally occurring grains and converted the energy they gained into work such as ploughing fields or transporting humans and goods. Wood, peat, or other organic combustibles were gathered locally, usually by the consumer, and converted into heat and light energy in a very primitive manner. During the Roman era and into the Middle Ages some hydro and wind-powered machines were included in the mixture, generally mills, but these were very local in their use and impact. Wind was also harnessed to power sailing vessels thereby helping to move goods, facilitate trading between states, and also for power projection purposes. Energy use changes involving animal, wind, and water took place over thousands of years.[2] Under these energy conversion constraints, development was extremely slow, and global economic productivity was quite low in comparison to contemporary levels.

Whale Oil

The use of whale oil to provide illumination around the world began in the mid 17th century after whalers discovered that they could harvest the oil from the whale. The world quickly embraced this technological evolution since it provided cleaner, more reliable, and brighter light than previous options such as the tallow candle. Whale oil provides an early example of an energy resource that required the development of a highly specialized and complex industry and infrastructure to extract the resource, prepare it for market, and sell it to consumers for final use. However, as demand grew and the industry began to harvest more whales, they became scarce in number forcing whalers to go further to find them. This, in turn, drove up the cost of the whale oil. In 1849 Canadian geologist, Abraham Gesner, devised a method for refining kerosene from bituminous tar leading to the development of kerosene lamps which were much cheaper then whale oil lamps but equally useful. This development led to the rapid decline of whale oil as a major source of illumination. The transition took roughly twenty years making it likely one of the shortest in the history of energy conversions.[3] It also laid the groundwork for the evolution to oil, although oil's early use was primarily for illumination so the oil age had not truly begun at this point in history.

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[2] Jared Diamond, *Guns, Germs, and Steel: The Fates of Human Societies* (New York: W.W. Norton and Company, 1997) 358-359.
[3] Peter Tertzakian, *A Thousand Barrels a Second* (New York: McGraw Hill, 2007) 8-23.

The Coal Age

It is difficult to pinpoint precisely when humans began to make use of coal as an energy source. The Chinese are believed to have been burning it for heat well before the current era. Scottish monks first made use of coal to heat their dwellings around the 9th century. Over time brewers and metal smiths began to use coal to carry out their crafts. As demand slowly grew a coal industry developed such that the resource was traded throughout England by the 14th century.[4] It was not until the early 18th century that inventors realized that steam produced using coal as a heat source could power industrial processes. In the beginning of the 18th century Thomas Newcomen invented the first steam engine that converted power from coal combustion to carry out work. James Watt made a more efficient version of this machine in the 1760s. Still, it was not until some point during the 1890s that coal became the source for over half of the world's primary energy.[5] Furthermore, it was not until 1910 that coal's dominance peaked at 60% of the world's total primary energy source.[6] The pace of this process was glacial at best. While the rate of the transition from previously dominant energy sources was slow, once it took hold, coal became a catalyst for industrial and societal change on an unprecedented scale. The development of steam engines and their conversion to suit many locomotive and industrial processes was revolutionary and set the pace for the industrial age.

Like the whale oil industry, coal required a global processing infrastructure to extract and distribute the resource to end users creating significant economic growth in the process. At the political state level, countries with large naval forces, the United Kingdom and Germany for example, began to consider coal as a strategic asset and set out to maintain replenishment points around the world. Coal also influenced the force development and doctrinal decisions taken by some militaries as their fleets and arms industries were increasingly powered by it. Coal powered metallurgy and industrial processes facilitated the development of metals more useful for weapons and ammunition. Moreover, ships powered by steam could now be built from steel in large numbers, increasing their durability and protection. They could also be more heavily armed than their sail powered predecessors. Consequently, warfare on land and sea was dramatically altered with the evolution of industry sustained by coal. These developments

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[4] Tertzakian. 26-27.
[5] Vaclav Smil, *Energy at the Crossroads* (Cambridge: MIT Press, 2005) 4.
[6] Roy L. Nersesian, *Energy for the 21st Century*. (New York: M.E. Sharpe, 2007) 80.

highlighted the importance of coal to the economic, political, and military development of the industrialized states.

Reliance on coal also created strategic vulnerabilities for some countries. If they did not possess enough of the resource domestically, states were forced to rely upon foreign suppliers. Also, for those countries that chose to project their power with naval forces reliance on coal necessitated the creation and protection of coaling stations around the world. Ships could only carry a limited amount and needed to refuel periodically. Historically, the transition to coal as a primary energy source marks a significant strategic development in that states became potentially vulnerable to supply disruptions of a strategically important resource and that resource began to drive military planning and development. Indeed, as Colin Gray noted,

> The wars, arms competitions, and other preparations for war of the twentieth century have all expressed the political, social, general economic, industrial, and especially technological conditions promoted by a particular source of power. In this view, the course of modern strategic history has been shaped successively by steampower, oilpower, and the power of the atom (as an energy source, as a weapon through fission and fusion, and as electronics).[7]

Thus, from the early industrial age through to the present, military forces have become strategically dependent on their primary sources of power. Used to their fullest potential, these energy sources have provided an advantage to modern militaries while denial of these same resources can result in crippling defeat.

Coal to Oil

As noted above, oil was initially used as a source of illumination. However, a number of inventors in the industrialized world began to experiment with development of an internal combustion engine as an alternative power source to either horses or steam-engines during the second half of the 19th century. The first commercial production of vehicles powered by refined oil products began in 1888 when Karl Benz opened up a car manufacturing facility in Germany. Other developers followed suit in Europe and the US so that, by the beginning of the

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[7] Colin S. Gray, *Modern Strategy* (New York: Oxford University Press, 1999) 185-186.

20th century, automobiles and small trucks powered by oil were starting to appear around the industrialized world.

Military planners saw the potential of these new engines and, as they had done with coal powered steam engines before, they began to push the development of the technology to improve their own capabilities. Oil powered ships were faster, had greater mobility because there were more refuelling options, could go to sea with 60% fewer personnel in the engine and boiler rooms, and needed half the fuel of their coal-powered counter-parts.[8] With these advantages, it is not surprising that military forces around the world made the transition to oil rather quickly.

One of the early proponents of oil as a source of power for military forces was Winston Churchill who, during his tenure as First Lord of the Admiralty, orchestrated a transition that has driven geopolitics from the early 20th century to the present day. Churchill's decision to convert the British naval fleet from coal to oil fundamentally redefined areas of strategic importance and launched the scramble for oil that will last until the end of the oil age. Not only did Churchill appreciate the advantage of oil-powered ships, he also understood the central tenant of oil security. As he eloquently stated on the eve of the First World War, "safety and certainty in oil lie in variety, and variety alone."[9] The variety that he referred to meant a variety of suppliers such that reliance on any particular source could be avoided. Developed and developing states have acted upon this axiom since that time.

Navies were not the only military forces that benefitted by the switch to gasoline and diesel. During the First World War, the belligerents all made use of vehicles powered by oil to move troops, equipment, and supplies. These included ships, airplanes, trucks, cars, motor-cycles, and tanks. Supplying these vehicles necessitated the development of an integrated supply-chain and infrastructure network beginning at the extraction site and ending at the fuel tank. Demand for these vehicles grew considerably during the war years. The pace of change did not abate following the First World War and technological innovation prior to World War 2 drove the strategy, operations, and tactics of the belligerents in that conflict. At the same time, strategists began to appreciate just how vulnerable

[8] Tertzakian, 36-38.

[9] "The real trouble with oil," *The Economist* (30 April 2005) 9.

they were to oil supply interruptions.[10] As had occurred during the Coal Age, military planners supported and directed a dramatic change in technology and strategy that was only possible because of this new energy source — oil. Their reliance on oil led to the creation of the vast network of infrastructure that endures and expands to this day. It also created new strategic challenges because military forces became dependent on this vital energy source to function and survive in the battlefield.

The transition from coal to oil as the dominant form of energy on a global scale was fairly lengthy. From its replacement of whale oil as a source of illumination to its rise to dominance as the leading primary energy source over a century passed. In part, the slow transition was attributable to the investment that industries, particularly railroads, had made in coal burning devices. While refined products from oil were more flexible in their use, had a higher energy density therefore less was required, and the machines that burned them were generally more efficient and lasted longer than their coal burning predecessors, business owners needed to absorb the significant costs of transition over time.[11] Consequently, coal supplied "more than 50% of the world's commercial energy until 1962, and it remained the single most important commercial fuel until 1966."[12] While governments could convert their military fleets without answering to shareholders or without significant concern for the bottom-line implications of this change, business and industry could not move as quickly.

Electricity and the Nuclear Age

While coal use fuelled the early industrial age, it was not until the late 19th century that the process of electrical generation and transmission began its role as a major source of adaptable power that spurred even more industrial development. Thomas Edison opened his first generating station on Pearl Street in New York in 1882 and began the era of electrical grids and the generation and transmission of power on a commercial basis. The ability to generate and focus electrical power spurred a technological boom that continues to the present. Economic growth has benefitted as has society in general because electricity can power a vast array of machines and devices that improve the quality of life for populations who have access to them. The development of generation and

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[10] Michael T. Klare, *Resource Wars*. (New York: Metropolitan Books, 2001) 29-32.
[11] Nersesian, 81-82.
[12] Smil, E*nergy at the Crossroads*. 15.

transmission capacity also resulted in construction and maintenance of a vast network of electrical infrastructure that moves the power to end-users throughout most of the globe. Over time, use of these electrically powered devices — particularly computers — has become essential to the functioning of societies and has created critical dependencies.

The development and commercialization of nuclear power owes much to the research and development undertaken to produce nuclear weapons during World War II. Following the end of the war, research to harness nuclear power commercially continued although there were equally ambitious programs to develop nuclear powered submarines at the same time. The first reactor capable of generating electricity was an experimental one that came online in December 1951 in the U.S.. Within a decade, five other countries connected nuclear power to the grid including the United Kingdom in 1953, the former Soviet Union in 1954, France in 1956, and Germany in 1961. More countries joined the nuclear power club throughout the coming decades with the energy crisis of 1973-1974 adding particular motivation for developing new plants.[13] The construction of new reactors has continued periodically since that time such that at the end of 2009 total global nuclear electrical generation capacity totalled 370 giga watts (electric) (GW(e)) spread amongst 437 operational reactors.[14] According to International Energy Agency (IEA) calculations, nuclear power accounted for 5.8% of the worlds total primary energy supply in 2008 and for 13.5% of all electricity generated.[15] However, since 2006, the overall amount of nuclear energy consumed has gone down slightly year on year[16] and it remains to be seen if this is a temporary downward trend or whether it will become a long-term trend. This issue will be examined later in this report.

Clearly, early development of nuclear energy owed much to the military interest on the part of several governments. Research and development of the first nuclear propulsion system began in the 1940s. The U.S. developed the first experimental nuclear marine propulsion unit in 1953 followed by the launching of its first nuclear powered submarine, the USS Nautilus in 1955. Nuclear powered submarines were a tremendous improvement over their non-nuclear predecessors in that they were faster, quieter, and where able to stay submerged

[13] Nuclear Energy Agency, *Nuclear Energy Today*. (Paris: OECD Publications, 2005) 9.
[14] International Atomic Energy Agency, *IAEA Annual Report 2009*. 1. Accessed on 18 April 2011 at http://www.iaea.org/Publications/Reports/Anrep2009/anrep2009_full.pdf.
[15] International Energy Agency, *Key World Energy Statistics 2010*. (Paris: IEA, 2010) 6 & 24.
[16] *BP Statistical Review of World Energy 2010*. (June 2010) 36-37.

for significantly longer periods of time than the conventionally powered versions. The United Kingdom, France, Russia, China, India, Japan, and Germany also developed their own nuclear powered surface and/or sub-surface capabilities. Nuclear powered shipping is no longer restricted to military applications as some ice-breakers, research vessels, and even merchant ships have been powered by nuclear propulsion systems.[17] This is example of an energy technology originally intended for military use that has had some applicability in civilian applications.

Lessons from Previous Energy Transformations

Understanding how energy transitions have occurred is important as it provides us with some guides as to how subsequent ones might transpire. A key point is that these transitions take considerable time. Recent transformations have spanned generations. Advocates of plans to change the global energy infrastructure in the next decade would do well to heed this historic lesson. There are several reasons for this pace but generally they relate to the investment in the existing infrastructure and equipment vested in the old primary energy sources. Infrastructure and equipment is exceedingly expensive so dramatic changes should not be expected in a rapid period of time. Also, development and refinement of the uses, safety, transportability, and other logistical considerations related to the scalability of the new sources of energy take considerable time. The speed of the investment is often a product of the price of the old resources. When the prices stay low, the motivation to change also remains low.

Another consideration is that even when a transition has occurred, the old energy sources remain. Coal is a case in point. As global thirst for energy, particularly electricity, grows so too does coal consumption in many parts of the world. So, even though the world's dominant primary energy source is still oil, there are other significant components that go into the energy mix and they will remain so long as their use is still practical, affordable, and safe or until something that is cheaper and equally useful is developed.

[17] World Nuclear Association, Nuclear-Powered Ships. Accessed on 18 April 2011 at http://www.world-nuclear.org/info/inf34.html.

Another important lesson from energy transitions is that along with society's increased dependence on a new source of energy there is also an increase in the strategic imperative to acquire and safeguard it. This strategic imperative has had considerable influence in the development of states' interests and their subsequent relations with other states. At times, it has led to armed conflicts. Similarly, for producers of the resource, this dependency can be used as a strategic advantage by either threatening or actually disrupting supply as will be examined below.

Finally, military forces can and do play a central and often leading role in the energy transition process. This is a symbiotic relationship as new energy sources are perceived to provide some advantage over the old choice. This leads to change initiated by the military to make a transition to the new source that, in turn, fosters investment in infrastructure and technology that maximize the utility and availability of the new energy resource. At the same time that these changes occur, the manner in which military forces can be employed can transform in response to the improved characteristics provided by the new energy resource. However, with opportunity also comes risk since the military can become dependent on a particular source of energy, denial of that source can have catastrophic impact.

3. The Energy Environment

Current and Forecast Energy Consumption

As Figure 1 shows, global energy consumption has increased on a year to year basis in recent years. The recent global economic crisis led to a slight drop in energy consumption worldwide and it has yet to regain its peak consumption level of 1,1315.2 million tonnes of oil equivalent (mtoe) established in 2008, although once the economic recovery gains momentum, energy consumption should continue to rise.

Figure 1: Global Primary Energy Consumption 1999-2009[18]

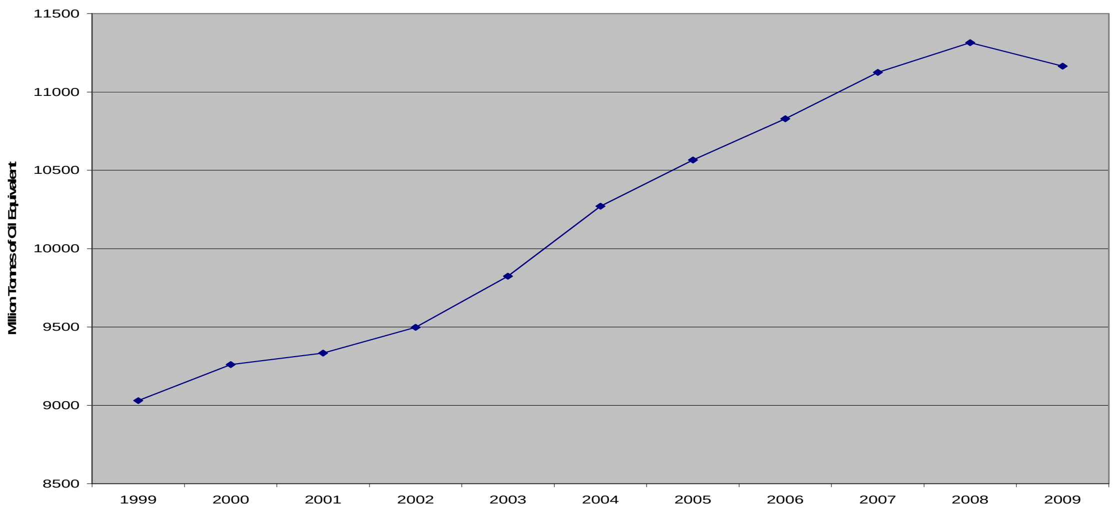

Figure 2 shows the recent consumption rates for the major energy sources and suggests their usage trends. It is noteworthy that the growth in consumption for both nuclear and hydro-electric power is relatively flat compared to natural gas and coal as well as oil. Although the oil consumption growth rate during the ten year period is not as sharp as those of gas and coal. This is because of two concurrent trends affecting energy consumption patterns in recent years. The first trend is that the transition from oil to gas is starting to impact the relative consumption growth rates of these two fossil fuels. From an environmental perspective, this should help to reduce the production of harmful emissions as gas is cleaner burning than oil. The second trend is that coal consumption is rising at an even faster rate than the other major energy sources. As the developing world continues to develop it adds more electrical generation capacity. However, much of it is from coal since coal powered generation is less expensive and quicker to install than other options. This unfortunately will have a negative environmental impact since even with the ongoing development of cleaner coal technology, it is still the most harmful emission source amongst the fossil fuels. Moreover, even with the development of clean coal technologies, many of the new coal generation plants are being constructed in poorer countries that are less able to afford these technologies.

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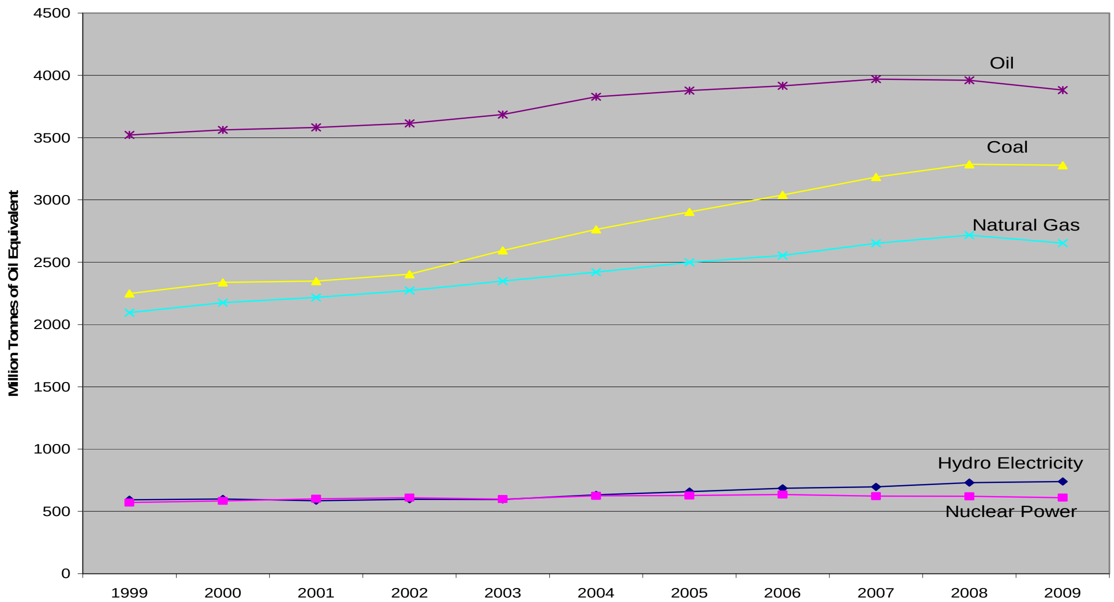
[18] Data for this chart was taken from *BP Statistical Review of World Energy 2010*. (June 2010) 40.

Figure 2: Energy Consumption by Major Sources 1979-2009[19]



Figures 1 and 2 provide a rough understanding of our contemporary energy consumption pattern and trends. What is not evident from Figure 2 is the growth of the contributions of alternate energy sources. Data on these sources is difficult to aggregate and comes from disparate sources. This is due, in part, to the relatively recent addition of these sources, such as solar, wind, and biomass to the global energy system. However, alternate energy sources have been playing an increasingly important role in powering the global grid and fuelling some of its transportation. According to recent IEA reporting, renewable energy sources have experienced growth rates of between 30% and 40% during the past few years.[20] According to the *Renewables 2010 - Global Status Report*, renewable energy comprised 19% of total energy consumed in 2008. To put that in perspective with Figure 2, hydro was included in the 19% and accounted for 3.2% of the total. Also, a full 13% was traditional biomass meaning wood burned to heat, cook or illuminate. So, according to this report, the amount of this total attributable to new, non-hydro renewable technology is 5.8% of global energy consumed in

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[19] Data for this chart was taken from *BP Statistical Review of World Energy 2010*. (June 2010) 12, 28, 35, 36, & 38.
[20] *Clean Energy Progress Report* (Paris: IEA/OECD, 2011) 11.

2008.[21] Given the interest and investment spent on many of these initiatives in recent years, it seems likely that this percentage will increase in the coming decades leading to some replacement of fossil fuelled technology by alternative energy powered capabilities. A short-term challenge to this growth will be the recent tendency to embrace austerity by many governments struggling to recover from the global economic crisis. It remains to be seen how long and how significantly these austerity measures will curb the growth in research and development for alternative energy sources.

Another vital component of information not evident from Figures 1 and 2 is the location in which this energy gets consumed. This is a very important detail when considering energy security. In many countries of the world, the discourse focuses on energy poverty rather than energy security. For the purposes of this research, energy poverty is the state of having insufficient energy on a regular and reliable basis to carry on continual and dependable economic, social, medical, and logistical functions. According to the *BP Statistical Review of World Energy 2010* global energy consumption in 2009 totalled 11,164.3 mtoe.[22] Of this total, 23.9% was consumed in North America (including Mexico), 5% in South and Central America, 24.6% in Europe and Eurasia, 5.9% in the Middle East, 3.2% in Africa, and 37.1% in Asia Pacific.[23] Clearly there is a significant inequity in the distribution of energy resource consumption throughout the world with Africa enduring the lowest amounts followed closely by South and Central America. While the Asia Pacific region consumed a large share, it is important to remember that the bulk of the world population lives in this region so on a per capita basis, its share of the total is not as extensive as its overall percentage might suggest at first glance. Unequal distribution of energy is important to keep in mind when considering energy statistics as it should be clear that certain regions are extremely energy poor and people in these regions will not have reliable access to the energy resources needed to sustain a healthy lifestyle and develop vibrant economies. From a security perspective, this is an important

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[21] *Renewables 2010 – Global Status Report*. Published by REN21 – Renewable Energy Policy Network for the 21st Century (September 2010). Accessed on 20 April 2011 at http://www.ren21.net/Portals/97/documents/GSR/REN21_GSR_2010_full_revised%20Sept2010.pdf

[22] This figure included commercially traded fuels only and did not include wood, peat, wind, geothermal, and solar power so is not exhaustive. However, using the renewable figures noted immediately above, these sources accounted for roughly 15.8% of global production in 2008 and were presumably close to that percentage in 2009. Divided amongst the various regions of the globe, their relevance for this particular section is reduced.

[23] *BP Statistical Review of World Energy 2010*. (June 2010) 40.

factor influencing the potential for conflict and is also a crucial factor for logistical considerations for deployed forces.

Looking to the future, it is difficult to accurately forecast energy use since technological developments often shake up the resource potential such as the world has seen in recent years with the growth in shale gas extraction capability. Advances such as this can add many years to the sustainability of a resource. Other uncertainties stem from the rate of economic growth. Typically, growth leads to or requires more energy consumption. Although, it depends where the growth occurs since most developed economies are becoming more efficient and require less energy per dollar of GDP than previously. Developing states are also benefitting from increased industrial efficiency so it remains to be seen how energy intensive future global economic activity will be. Of course another major influence on future energy consumption will be population growth. The UN *World Population to 2300* report of 2004 forecasted that the global population in 2050 will likely reach 8.9 billion people, a 48% increase from the 2000 population of 6.1 billion.[24] There will be a requirement for more energy to sustain a growing population. The IEA has forecasted a baseline scenario of overall global energy consumption out to 2030 to grow at a rate of 1.5% per year for an overall increase of 40% compared to 2007 consumption. It estimates in this scenario that consumption in 2030 will reach 16.8 billion tons of oil equivalent (btoe).[25] It remains to be seen where the necessary supply will come from. It is possible that the world will be adequately supplied or it may be that certain resources might be in scarce supply leading to shortages, price spikes, and even conflict as competition for them grows more intense.

The End of Oil?

In recent years there has been considerable analysis of the perceived pending end of the oil age. The contemporary fear that oil will reach its peak production level and rapidly decline is not a new idea. Its recent iteration can be traced to renowned geophysicist M. King Hubbert who posited that the total U.S. production of conventional oil would amount to roughly 150 billion barrels and its production peak of 2.6 billion barrels per year would arrive around 1965. He allowed that the total of U.S. production could amount to 200 billion barrels in

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[24] United Nations Department of Economic and Social Affairs – Population Division, *World Population to 2300*, ST/ESA/SER.A/236 (2004) accessed on 21 April 2011 at http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf.
[25] International Energy Agency, *World Energy Outlook 2009* (Paris: OECD/IEA, 2009) 74.

which case the peak production of 3 billion per year would occur around 1970. Hubbert did acknowledge that with enhanced recovery techniques, the overall oil production amounts could increase although he believed that these enhancements would not impact his peak production forecasts rather that they would simply decrease the rate of the production declines slightly. He also posited that once oil production peaked, it would begin a rapid decline leaving the world without enough oil to properly function in a relatively short period of time.[26] Hubbert's worrisome predictions have been resurrected recently by authors such as Colin Campbell, Kenneth Deffeyes, Andrew Flower, and Jean Laherrère.[27] His thinking has also spawned the creation of a global association known as the Association for the Study of Peak Oil and Gas (ASPO)[28] that has chapters in many countries throughout the world. Proponents of Hubbert's peak oil theory have offered up a plethora of dates for the peak and have suggested various bleak scenarios for global security in its aftermath. Several of these dates have already passed and thankfully, the peak has not occurred nor has the world suffered any of the dire consequences some peak oil theorists have predicted.[29]

While Hubbert was correct on his estimated peak oil timing for the U.S., as Figure 3 illustrates, he was off significantly on the amount of oil at the peak and also the rate of production decline thereafter. Annual U.S. oil production peaked in 1970 at 3.517 billion barrels, roughly 17% higher than Hubbert's largest estimate. Moreover Hubbert's graph indicates that his high estimate of U.S. oil production in 2000 is approximately 1.5 billion barrels whereas the actual total was 2.13 billion barrels — roughly 42% higher than predicted.[30]

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[26] M. King Hubbert, "Nuclear Energy and the Fossil Fuels," Presented to the American Petroleum Institute, Plaza Hotel, San Antonio, Texas (March 1956).

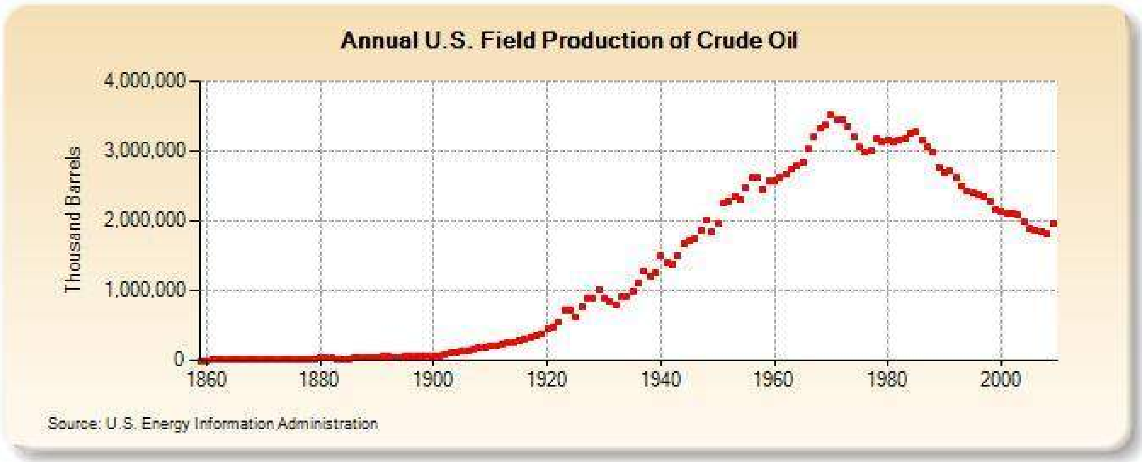
[27] Colin Campbell, *The Coming Oil Crisis* (London: Multi-Science Publishing Co. Ltd., 2004). Jean Laherère, "World Oil Supply - What goes up must go down: When will it peak?" *Oil and Gas Journal* (February 1999) 57-64. Andrew Flower, "World Oil Production," *Scientific American* 238 (3) (1978) 42-29. Kenneth S. Dreffeyes, *Hubbert's Peak: The Impending World Oil Shortage* (Princeton: Princeton University Press, 2009).

[28] www.peakoil.net.

[29] Vaclav Smil, Global Catastrophes and Trends – The Next Fifty Years (Cambridge: The MIT Press, 2008) 78-81. See also John H. Wood, Gary R. Long, and David F. Morehouse, "Long-Term World Oil Supply Scenarios – The Future is Neither as Bleak or as Rosy as Some Assert," (2004) 2. Accessed on 22 March 2011 at http://www.eia.gov/pub/oil_gas/petroleum/feature_articles/2004/worldoilsupply/pdf/itwos04.pdf

[30] The figures for actual US production in 1970 and 2000 were published by the US Energy Information Agency, "US Field Production of Crude Oil," accessed on 22 March 2011 at http://www.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MCRFPUS1&f=A.

Figure 3: Annual U.S. Crude Oil Production 1859-2009[31]



In 1969 Hubbert predicted that global oil production would peak at either 25 billion barrels in 1990 or 37 billion barrels in 2000. On both estimates Hubbert was significantly wrong. Hubbert's models for these estimates were symmetrical curves based on the assumption that consumption would continue to grow as it had up to the point he made the predictions. He did not take into account the dramatic drop in demand that would result from the oil shocks of 1973-74 or 1979-81 when OPEC drove up global energy prices through embargo and supply disruption.[32] Global oil production in 2000 was roughly 27.3 billion barrels or approximately 26% below Hubbert's prediction. While there was a drop in global production of approximately 2.6% between 2008 and 2009[33] it was not due to world production peaking in 2008, rather it can be attributed to the global economic crisis that resulted in significant demand reduction throughout most of the world.

Another reason why Hubbert's model has proved inaccurate at predicting resource decline is that it underestimates ultimate recoverable resource levels and does not account for growth in production in older fields.[34] Technology to enhance recovery from oil fields is constantly improved so that a higher

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[31] US Energy Information Agency, "US Field Production of Crude Oil," accessed on 22 March 2011 at http://www.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MCRFPUS1&f=A.
[32] Vaclav Smil, *Energy Myths and Realities* (Washington: The AEI Press, 2010) 64.
[33] Production data come from *BP Statistical Review of World Energy2010* (June 2010) 8. The percentage error calculations were made by the author.
[34] Richard Nehring, "Post-Hubbert challenges is to find new methods to predict production, EUR," *Oil and Gas Journal* 104, 16 (24 April 2006) 43 and 46.

percentage of oil recovery is possible from most fields than was the case when Hubbert did his work.

Hubbert's forecast for ultimately recoverable resources was also limited by incomplete exploration data. During the period of his research there was less knowledge of reserves and potential reserves than exists today. As a result, Hubbert's assessment of the global ultimate recoverable oil was 1.25 trillion barrels.[35] As technology has improved, previously unrecoverable reserves have become viable. Moreover, there has been a significant amount of exploration since he wrote so more production areas have been located. A more recent assessment by the U.S. Energy Information Agency (EIA) using a different methodology and based on much more thorough database than Hubbert, forecasts a range of ultimately recoverable oil with a low forecast of roughly 2.25 trillion barrels and a high forecast of approximately 3.9 trillion barrels. The mean value for the EIA assessment is 3.0 trillion barrels.[36] It is important to keep in mind that even this EIA report is based on currently available recovery techniques. It is not possible to know what improvements to these techniques might occur in the coming years so these estimates may also prove conservative over time.

Clearly fossil fuels are finite resources, or at least their reproduction time is so lengthy that the amount available to the human race will not increase at a rate sufficient to replenish them for our use. However, the dire predictions made by Hubbert and those that support his thinking have been proven wrong and should not be guiding strategic resource decisions. The EIA report presents several forecasts for the global peak oil period as reproduced in Figure 4. As this figure indicates, depending on the ultimate recoverable amounts and depending on the rate of consumption, the production peak can be expected to occur somewhere between 2021 and 2112, although the outlying dates are the least likely.

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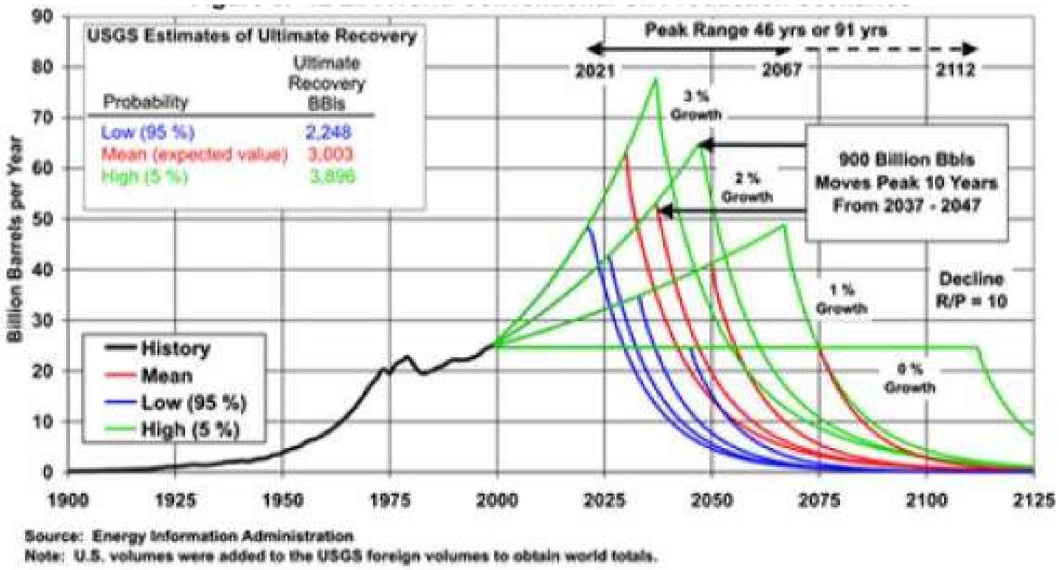
[35] Hubbert, "Nuclear Energy and the Fossil Fuels."

[36] John H. Wood, Gary R. Long, and David F. Morehouse, "Long-Term World Oil Supply Scenarios – The Future is Neither as Bleak or as Rosy as Some Assert," (2004) 6. Accessed on 22 March 2011 at http://www.eia.gov/pub/oil_gas/petroleum/feature_articles/2004/worldoilsupply/pdf/itwos04.pdf

Figure 4: 12 EIA World Conventional Oil Scenarios[37]



The reality is the oil will never truly "end." Rather it will be replaced by other forms of energy that become relatively less expensive. As easily accessed oil reserves become depleted, oil companies are forced to extract the resource from more difficult fields or they are forced to harvest heavier and more expensively processed sources such as oil sands or heavy oil. The so-called "easy oil" is being consumed. Consequently, the prices for oil are likely to rise or stay high over time given the IEA's forecast for 2030 global oil demand will rise to 105.2 million barrels per day (mbpd)[38] from just over 84 mbpd consumed in 2009.[39] Sustained high prices will encourage substitutions such that other energy sources will reduce oil use and end its dominance of world energy markets in the future. It is not likely that any one resource will do so; rather substitutions will come from several sources as outlined below. This progression is already happening in some measure as processes that were once done using oil, such as heating, electrical generation, and some transportation are now being done using natural gas, geothermal, solar, and wind power. This slow transformation will provide challenges to those who do not adapt in a timely manner, but it will also provide opportunity for those who adapt to this change and lead the way with new ways to power energy dependent activities.

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[37] Wood et. al. 6.
[38] International Energy Agency. *World Energy Outlook 2009*. (Paris: OECD/IEA, 2009) 81.
[39] *BP Statistical Review of World Energy2010* (June 2010) 11.

Capacity Challenges

In addition to the decline in the amount of easily processed oil and consequent increased production costs, there are other factors that are influencing high prices. A major challenge is the narrowing gap between supply and demand that has periodically driven prices up in recent years.[40] Market supply scarcity and the resultant price pressures are not attributable to an inadequate resource base. Rather they are influenced by the tight capacity of the global oil market to meet demand.

The key process that challenges the market's capacity is refining. It seems counter-intuitive that in an industry with such potential wealth that after over a century of building infrastructure there are capacity challenges. However, it is not considering that investments in refineries are extremely expensive, time-consuming, and the pay-back time is often measured in decades. During the 1990s investments in refining and marketing activities garnered less than a 5% return. This was lower than the cost of borrowing during this period so it is not surprising that there was little financial incentive for companies to spend on new infrastructure.[41] From the 1970s until recently there were very few refineries constructed globally.[42] In the U.S. — long the world's biggest consumer of oil — there have been no refineries built since 1981 and the number of facilities operating has fallen from 325 to 149 since that time.[43] Consequently, refinery capacity in the U.S. fell from 17.9 million barrels per day mbpd in 1981 to a recent low of 15 mbpd in 1993. Global capacity also fell from a 1980 high of 79.4 mbpd to a low of 72.7 mbpd in 1986. Since that time it has increased slowly to a rate of approximately 90.7 mbpd in 2009.[44]

Adding to the financial challenges to increased investment in refinery capacity, there are those stemming from OPEC policies. OPEC, whose members control roughly 70% of global proved reserves and includes eleven of fifteen of the

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[40] Serhan Cevik and Tahsin Saadi Sedik, "A Barrel of Oil or a Bottle of Wine: How Do Global Growth Dynamics Affect Commodity Prices?" *IMF Working Paper*. WP 11/1 (International Monetary Fund, 2011). International crises, be they of human or natural origin, also play a role in price spikes – witness the impact of the crisis in Libya on the price of oil at the time of writing (Mar-Apr 2011).
[41] D.J. Peterson and Sergej Mahnovski, *New Forces at Work in Refining*. (Santa Monica: RAND, 2003) 60-61.
[42] Mark Clayton, "A push to build new U.S. refineries," *Christian Science Monitor*. (September 21, 2005).
[43] Shawn McCarthy, "Refineries: Needle edging closer to empty," *Globe and Mail* (May 25, 2005).
[44] These figures are from the historical data section of the *BP Statistical Review of World Energy 2010*. (June 2010) website http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622 accessed on 13 April 2011.

world's top producers, attempts to control oil prices in two ways. One, and perhaps the most known, is through its quota system that aims to control the amount of oil available to the market. However, this method is notoriously ineffective as most member states have a long record of ignoring OPEC quotas in order to better serve their interests. The other way that OPEC attempts to control prices is by limiting the growth of new capacity. Arguably, this method has been more effective since it has contributed to a long-term upward pricing trend that benefits the producers. It is noteworthy that OPEC's crude oil production capacity of 34 mbpd has remained largely unchanged since 1973.[45] OPEC has indicated that it will not commit to significant upstream development unless demand keeps oil prices above $70 USD per barrel.[46] Yet, as the head of the International Energy Agency (IEA), Nobuo Tanaka points out, this price requirement for new investment is unnecessarily high given that the Middle East production costs range between $10 and $20 USD per barrel.[47] It seems possible that OPEC will continue to restrain capacity investment in order to keep prices high.

Contemporary refinery capacity is adequate to meet consumption requirements — throughput in 2009 was 73.5 mpbd whereas the refinery capacity for that year was roughly 90.7 mbpd leaving roughly 17.2 mbpd or 18% spare capacity — so the potential challenge to energy security is not immediate. However, spare capacity is an absolute necessity given the requirement to conduct maintenance and upgrades at the refineries. It is also important to note that global oil demand in 2009 was still dampened by the slow recovery from the economic crisis. Over time, demand will rise and with it, the need for more refined products. This will narrow the spare capacity margin unless more capacity is brought on-stream. If the slope of the demand curve exceeds that of new refinery capacity, the world could face a new oil crisis brought on by capacity short-falls. Consumer states can offset capacity-related shortfalls for limited periods by utilizing strategic oil reserves, however current global reserve levels may be insufficient to offset shortages for lengthy periods, particularly in light of anticipated demand increases.

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[45] James L. Smith, "World Oil: Market or Mayhem?" *Journal of Economic Perspectives*. Vol. 23, No. 3 (Summer 2009)150-153.
[46] "Opec: give US certainty to invest," *Petroleum Economist*. 3/10 (March 2010) 4.
[47] "Huge Opec investment in upstream oil capacity needed, says IEA," *Petroleum Economist*. 4/10 (April 2010) 4.

Enhanced Extraction and Supply

As noted above, the transition from reliance on oil is already underway. In recent years, many of the processes that used to require oil are being done using natural gas. Gas also poses an environmental challenge in that it too produces CO_2 when it burns contributing to global Green House Gas (GHG) emissions. However, it burns more cleanly than oil producing 40% less carbon emissions so it is a cleaner choice.[48] While gas is a fossil fuel and therefore a finite resource, its conventional reserve situation is much better than oil. The International Energy Agency (IEA) *World Energy Outlook 2009* estimates that in 2009 there were 400 trillion cubic metres (tcm) of conventional recoverable gas reserves — that is enough to last more than 130 years at current consumption rates. The report also indicated that there are roughly 900 tcm of unconventional gas resources and based on these the IEA suggests that the total recoverable gas resource base is approximately 850 tcm.[49] Clearly there is enough gas to last much longer than oil.

Access to the unconventional gas reserves has improved dramatically in recent years due to significant technological innovation. These developments have facilitated a revolutionary change in the gas industry by enabling the extraction of tight gas, shale gas, and coal-bed methane on a commercially profitable basis. These non-conventional gas reserves benefit energy security generally by increasing global supply to the markets. Shale gas in particular is starting to take over a large share of production in the U.S. market (23% in 2010) and a recent U.S. Energy Information Administration report estimates that there are 48 shale gas basins in 32 countries around the world. It estimates the technically recoverable amounts of gas in these basins at 6,622 Trillion Cubic Feet (Tcf). Total global recoverable gas, not include the shale gas, is estimated at 16,000 Tcf so the added shale gas increases this amount over 40% to over 22,000 Tcf.[50] Locally produced gas can also reduce or eliminate dependence on external suppliers for country's that possess these resources. Central Eastern Europe is a case in point in that it is believed to possess substantial amounts of non-conventional gas resources.[51] Exploiting this gas will provide the countries in the region with

[48] David Howell and Carole Nakhle, *Out of the Energy Labyrinth* (London: I.B. Tauris, 2007) 33.
[49] International Energy Agency, *World Energy Outlook 2009* (Paris: OECD/IEA, 2009) 389.
[50] Energy Information Administration, *Today in Energy – Shale gas is a global phenomenon*. (5 April 2011). Accessed on 24 April 2011 at http://www.eia.gov/todayinenergy/detail.cfm?id=811.
[51] Maximillian Kuhn and Frank Umbach, "Strategic Perspectives of Unconventional Gas: A Game Changer with Implications for the EU's Energy Security," *A EUCERS Strategy Paper*. 01:01 (May 2011).

supply options and reduce their need to rely on Russian gas as they have done for decades. Recent interruptions to Russian gas exports increase the incentive for these countries to develop the non-conventional resource and increase their own domestic production.

Liquefied Natural Gas (LNG) is not a new source of gas since it has been commercially available for decades. However, it is worth noting that it provides countries with more flexible supply options. LNG facilitates the trading of gas as a spot market commodity, similar to oil, rather than a commodity whose price is agreed between producer and consumer via long-term contracts that risk placing one of the parties at a disadvantage when the production costs vary significantly from the agreed contractual price. A spot market for gas should increase competition and reduce the ability of suppliers to create economic hardships for consumers or use the resource as a political tool by interrupting exports. Essentially LNG could encourage suppliers to be more reliable since failing to do so will lead consumers to seek alternate supply.

There has been considerable attention paid to the energy potential of the Arctic in recent years. The grounds for this attention is twofold: first, with the ice-melting trend there is a perception that the Arctic may be more accessible to ships and drilling platforms than previously; second, it is believed, with some certainty, that the region possesses significant fossil fuel reserves. Studies suggest that up to 13% of the global undiscovered oil and up to 30% of the global undiscovered gas lies in the Arctic. Estimates for gas hydrates suggest even more potential in the region for this, as yet commercially unharnessed energy resource. Production of oil and gas has been occurring in the Arctic for decades and some analysts believe that the potential to expand operations exists. This is not without controversy however as the regional ecosystem is very delicate so environmentalists are very critical of efforts to expand extraction there. Moreover, the technical challenges of operating in this harsh environment will increase the costs considerably for oil and gas companies.[52]

Gas hydrates are another significant source of gas that offer hope for future supply. It is estimated that there are between 6-600 times the amounts of gas hydrates as conventional gas in the world so this is potentially an enormously important supply for the future. Gas hydrates typically exist as methane and

[52] Peter F. Johnston "Arctic Energy Resources and Global Energy Security," *Journal of Military and Strategic Studies* 12-2 (Winter 2010) 1-20.

water frozen into a solid beneath the seafloor or permafrost regions. They are particularly attractive because the methane in them is concentrated due to their crystal structure resulting in a density of 164 m^3 of methane gas in each 1 m^3 of methane hydrate. The challenge is that gas hydrates are extremely difficult to extract without risking environmental disasters. The principle risk is that the methane, a green-house gas, will escape into the environment in an uncontrolled manner. Work continues to find a safe way to extract this resource and some estimates suggest it may be commercially viable before 2030.[53]

The growth in options for gas extraction will be beneficial to global energy security currently and into the future. Already there is a move to convert some functions traditionally fuelled by oil such that they will be powered by gas. This conversion process should reduce demand for oil, or at least slow demand growth, such that its useful life can be extended and some of the price pressures might be reduced. Gas has already replaced oil for power generation, heating, and industrial processes in many parts of the world.[54] Natural gas is also being used to replace oil as a fuel for vehicles. The U.S. is engaged in converting some of its vehicles to gas in order to reduce oil consumption. U.S. President Obama stressed the need to increase the number of gas-powered vehicles when he announced the *Blueprint for a Secure Energy Future* at Georgetown University in Washington on March 30, 2011.[55]

These types of substitutions are likely to continue given the continued high prices for oil. Sustained high prices have led many companies to consider plans to produce diesel and gasoline from gas (gas to liquid – GTL) using the Fischer-Tropsch process. South Africa's SASOL has experience using Fischer-Tropsch not only to convert gas but also uses coal to produce liquid fuels. While there is some disagreement about the economic break-even point for using this process, it seems that with oil over $80 a barrel, companies can profit.[56] Processes and developments such as these will likely extend the practical and economic use of fossil fuels further into the future.

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[53] R.A. Dawe and S. Thomas "A Large Potential Methane Source — Natural Gas Hydrates," *Energy Sources, Part A.* 29 (2007) 217-229. See also Keith A. Kvenvolden, "Gas Hydrates — Geological Perspective and Global Change," *Reviews of Geophysics* 31-2 (May 1993) 173-187.
[54] Howell and Nakhle, 33.
[55] *Blueprint for a Secure Energy Future* (30 March 2011) accessed on 31 March 2011 at http://www.whitehoUSe.gov/sites/default/files/blueprint_secure_energy_future.pdf. See also Shawn McCarthy, "Obama signals new reliance on oil sands," *The Globe and Mail* (30 March 2011).
[56] Nathan Vanderklippe, "Synthetic fuel sees new life," *The Globe and Mail* (18 March 2011).

Alternate Energy Sources

Concerns over the sustainability and environmental impact of fossil fuels have fostered significant research and development of alternate energy sources for electrical generation, heating, and transportation as well. Some proponents of these alternatives argue that they will be able to replace fossil fuels completely in a short period of time. Replacement times in this short range are unrealistic given the tremendous amount of technology and infrastructure investment that they would entail. Moreover, while many of the alternatives are promising, indeed some are meeting their promise; the upper limits of their potential contribution are often grossly overstated by their advocates. Even with these limitations, there is much promise in the realm of alternate energy and their incorporation into the future energy mixture will continue. This section will examine some of the major alternate energy sources under development and highlight their strengths and weaknesses as they are currently understood.

Wind Power

As noted above, wind has been harnessed to power human activities for thousands of years. However, recently, the commercialization of wind power to generate electricity has occurred on a large scale. Global installed wind power generation capacity has grown from roughly 18 Giga-Watts (GW) in 2000 to 195 GW in 2010.[57] This is an impressive achievement and more potential exists. However, there are limits to wind power's potential. One issue is the availability of suitable wind power generation sites. Not all parts of the world have wind speeds consistently in the range required to make this type of electrical generation practical. There is a wide body of literature that supports different sides of this issue, and it is not the intention of this paper to come to a definitive answer. On balance though, it seems that the current technology will only be able to harness a small percentage of the earth's total wind potential. One credible study places this figure at 8%.[58] Many of the best sites for harnessing wind power are located considerable distances from the centres where the electricity is required. Consequently, a massive amount of high voltage long-haul transmission lines would be required to move this electricity to the markets where it is needed.

[57] International Energy Agency, *Clean Energy Progress Report*. (Paris: OECD/IEA, 2011) 44.
[58] Smil, *Energy Myths and Realities*. 123.

Another limitation is related to scalability. Wind turbines used to generate commercial electricity typically generate up to 2 Mega-watts (MW) so to match standard coal-fired plants in the 400 MW range or nuclear plants in the 1,000 MW range, many turbines are needed but it is not just a matter of simple multiplication because wind farms cannot generally match the utilization rates of traditional plants.[59] Consequently, many turbines are needed to generate equivalent amounts of electricity achievable through traditional plants. This drives up the cost and manufacturing times to build, transport, erect, and connect the turbine capacity to replace many of the traditional plants.

An additional cost is maintenance of the turbines. This may prove to be more costly than expected as the design-life goal of twenty years for the gearboxes — the most expensive part of a turbine — is consistently not met. Gearbox failure has plagued the turbine industry since inception, and it does not seem to be generally from inferior manufacturing processes or components. The stresses placed on the gearboxes are such that this crucial component cannot meet life-cycle performance expectations. Considerable research and development to improve the life expectancy of gearboxes has been occurring for decades and will continue.[60]

Another challenge with wind power generation is the consistency of the winds. Even in regions with wind speeds sufficient to generate electricity, there are lulls when the turbines will not be turning quickly enough to generate electricity. Backup systems or storage capacity will be necessary to meet load requirements during these times. Backup systems require easy on and off capability. Currently, electricity generated by burning fossil fuels is the surest bet in this regard since it is easily turned on or off relative to nuclear power. Storage of the energy from wind power can be done by pumping water up to elevated reservoirs and then running it through turbines when the wind speeds are low. This option is not practical in all parts of the world since it depends on ready access to large amounts of water and a topography that features the necessary changes in altitude to power the turbines. If either of these components is absent, significant engineering or logistics fixes are necessary and in many cases these are too costly. As battery technology improves, other storage options may present, although again the costs will likely be significant. So, wind power generation

[59] Tertzakian, 206-207.
[60] W. Musial, S. Butterfield, and B. McNiff, "Improving Wind Turbine Gearbox Reliability," *Conference PaperNREL/CP-500-41548* (May 2007).

will certainly replace some of the fossil fuel plants existing today. However, they will not do universally as some advocates suggest.

Despite these challenges, it is clear that wind power generation will continue to grow for the coming decades. Large farms are providing a clean alternative to other options in centralized applications connected to the grid. Wind power can also be effective in a decentralized or localized grid environment.[61] Military forces can benefit by this localized grid or completely decentralized use of wind turbines.

Solar Power

Like wind power, there has been substantial investment in solar power technology in recent years. Amongst the G20 countries a total of $79 billion USD was invested in 2010 and 17 GW of new generating capacity installed, setting a record.[62] By end 2010 there was an estimated 40 GW of electricity generated by solar photovoltaic cells in the world; up from 1.5 GW in 2000.[63] Technology continues to improve such that the cells are more effective today than they were previously. Like wind power, solar power is best suited for only certain parts of the world. Many areas do not receive enough daily sunlight to warrant investing in solar cell technology. Storage is also a problem given the limited hours of sunlight. Clearly solar power will help to produce limited amounts of electricity in some regions and, where suitable, can provide a relatively quick generation capacity that can be installed and removed as required. As the technology improves, the deployment of photovoltaic panels has become less intrusive as they can now form part of the building materials in new construction or renovations. This lowers their environmental footprint.[64]

Already there are small portable systems available on the market to provide power off the grid. Military forces can make use of these systems to generate power at the small unit level. At the base level, there are examples in the US where bases are powered by numerous banks of photovoltaic cells. The US and

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[61] David M. Sweet, "The Decentralized Energy Paradigm," *Energy Security Challenges for the 21st Century* edited by Gal Luft and Anna Korin (Santa Barbara: ABC CLIO, 2009) 311.
[62] Pew Energy Group, *Who's Winning the Clean Energy Race*. (2011) 7.
[63] International Energy Agency, *Clean Energy Progress Report*. (Paris: OECD/IEA, 2011) 46.
[64] Sweet, 311-312.

Spain also lead the world with the largest commercial solar plants.[65] Like wind power, there is potential for capacity growth for solar power generation.

Solar energy is also used to heat water and buildings in some parts of the world. The main locations are China, Europe, the U.S., and Canada.[66] This too is an option for deployed military operations or bases provided they are located in parts of the world where there in sufficient amounts of sunlight with adequate intensity to provide the necessary thermal energy.

Geo-Thermal Energy

Geo-thermal heat is another environmentally friendly form of heating, cooling, and electrical generation that is increasingly being used in some regions. It is likely that global geo-thermal energy use will grow in the future as the technology to harness it improves. Iceland provides an example of the potential of this source in that approximately 75% its electricity is generated by geo-thermal energy and most of its houses and buildings are heated by it. However, it is important to note that Iceland is situated over readily accessible geo-thermal heat sources due to the active volcanic topography which characterizes the country.[67] Very few places in the world, at least the densely populated world, share this same characteristic. The leading producer of geothermal electricity in 2010 was the U.S. with 3,086 MW capacity followed by the Philippines with 1,904 MW.[68] Where it is available, geo-thermal energy will make a very suitable source of heating, cooling, and electrical generation.

Bio-Fuels

There are several alternative sources of energy under development for the transportation sector. One that is already having some impact in reducing fossil fuel use is crop-based bio-fuels. The idea is attractive — on the surface — in that it replaces fossil fuels that cause considerable damage to the environment with a renewable resource. Bio-fuel development enjoys considerable legislative and financial support in many industrialized nations and regions. Several countries have already embarked upon bio-fuel production programs with Brazil being

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[65] Op. cit.
[66] International Energy Agency, *Clean Energy Progress Report*. (Paris: OECD/IEA, 2011) 47.
[67] Andy Soos, "Icelandic Geothermal Energy," *Environmental News Network*. (8 March 2011). See also Daniel Gross, "Iceland has Power to Burn," *Newsweek.* (5 April 2008).
[68] Soos.

prominent for the sugar cane model, the US for corn, and soy-beans, palm-oil, or rapeseed in Europe.

Yet, there are several reasons why bio-fuels are not only impractical; they are a destructive and counter-productive option. The foremost reason is that they are starting to have a negative impact on the global food chain. Crops grown for fuel reduce the amount of arable land that can be used for food production.[69] Proponents of cellulosic ethanol argue that their preferred method uses the waste product of food production, largely stocks and leaves, and is therefore a much less disruptive method. However, this argument fails to acknowledge the importance these deleterious substances play in the food cycle by naturally fertilizing and rejuvenating the soil when they decompose. Removing these substances would necessitate even more fertilizer use; this too would be harmful to the environment. While sugar cane ethanol requires fewer acres of soil than do other methods, it is important to consider that fewer areas of the world are suitable for sugar cane cultivation. Moreover, much of the regions that are suitable are already being used to produce food so, like other methods of ethanol production, sugar cane based production has a negative impact on the food chain.[70] Given that there are limited amounts of land suitable for food production, it seems imprudent to dedicate increasing amounts of it to the production of ethanol.

More problematic is the incentive to clear more land for bio-fuel production leading to deforestation in many parts of the world. This is a significant environmental challenge in that forests are typically carbon sinks, that is, they absorb CO_2 thereby helping to reduce the impact of burning fossil fuels. Reducing these natural sinks is likely to have significant negative environmental repercussions.[71]

Electric Cars

Electrification of vehicles is also another option to reduce the consumption of fossil fuels. While many people are not aware, electric cars were amongst the first cars produced. At the turn of the 20th century it was possible to travel by electric car from New York to Philadelphia as there were six charging stations along the

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[69] Michael Grunwald, "Seven Myths About Alternative Energy," *Foreign Policy* 174 (September/October 2009) 130.
[70] Smil, *Energy Myths and Realities*. 98-115.
[71] Peter W. Huber and Mark P. Mills, *The Bottomless Well*. (New York: Basic Books, 2005) 160-163.

route. Boston had thirty-six charging stations by 1903.[72] However, it was the low cost and flexibility of gasoline that won the day relegating electric cars into the background until recent decades when interest and development of electric cars began again. Still, there are many hurdles to be successfully surmounted if electric cars can dominate global automobile markets. Amongst these is the availability of technologically advanced batteries necessary to store the charge that powers the vehicle. Added to this challenge will be the requirement of disposing of the batteries once they have reached the end of their life-cycles. During their lives, the effectiveness of the batteries will be dependent on climate in that batteries do not perform as well in extreme heat or cold. This will have a negative impact on the performance of these vehicles in many parts of the world save for those very rare areas with a year-round moderate climate.

Another problem facing mass electrification of transportation will be the need to increase electrical generation capacity sufficiently to meet the increased demand as more electric cars are brought online. Imagine the requirement if the current global vehicle fleet were to be converted then add to that the number of new vehicles in the future as more people in newly developed countries, particularly China and India, purchase cars. It seems that contemporary loads will have to increase by multiples if they are to meet the new demand. This begs the question: how will this electricity be generated? In many cases, the answer will be with fossil fuels meaning that impact of electric cars on the environment might be malign. In light of these challenges it seems very unlikely that the world will witness a complete transformation of its ground transportation to electric power. More likely, niche forms of transport such as railways or local short-haul industrial vehicles such as fork-lifts will see the largest transformation.

Hybrid Vehicles

A growing number of vehicles manufactured in recent years operate with a hybrid system that allows them to run on fossil fuels for some portions of their journey and on electricity for others. These vehicles, soon to be commercially augmented by plug-in hybrids, significantly reduce fossil fuel consumption as compared to vehicles powered solely by fossil fuels. Moreover, they do not rely as heavily on battery power as do the electric powered vehicles considered previously. This makes their development less challenging from an environmental perspective and also more in tune with existing technology.

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[72] Smil, *Energy Myths and Realities*. 19.

Moreover, because they generate their own electricity to charge their batteries, the overall impact on electrical consumption is negligible. Proponents of the plug-in versions argue that they will have an insignificant impact on the electrical grid if they are only charged at night. This is because historically electricity demand drops significantly overnight freeing generation capacity that could be utilized by these plug-in hybrids during that period.[73] It remains to be seen if these plug-in variants will saturate the market and, if so, what the charging habits of their owners will be.

Hydrogen Fuel Cells

Hydrogen fuel cell technology has also been suggested as a likely replacement to power vehicles. In small quantities, there has been success in creating these fuel cells and powering vehicles with them. However, like the other options outlined above, there are critical challenges that are likely to prevent a wholesale transformation to hydrogen powered transportation. Key amongst these is the need to produce enough hydrogen to allow the cells to be charged up. Creating this hydrogen usually relies on burning natural gas so this system is also dependent on the consumption of a fossil fuel. It can be generated using water although this is a very energy intensive process using electricity so the net energy benefit is questionable and potentially costly. Moreover, transformation to hydrogen power would necessitate the construction and financing of a very costly global hydrogen refuelling network. Hydrogen is difficult to liquefy so transportation would be a challenge and it also escapes through the smallest of cracks so safety would be a challenge.[74] Like electric vehicles, it is likely that hydrogen fuel cells will continue to power some vehicles but in niche markets only. Urban mass transit is one potential option as are small vehicles at industrial plants.

There are a number of other technologies that have been or are being developed to harness energy found in nature and convert it to power for our use. Ideas such as wave-power, tidal-power, deep-water conversions are just a few of the many options that are being explored. While some of these may add significantly to global energy production at some point in the future, it seems unlikely that they will do so presently. As noted above, energy transformations take decades, even

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[73] Paul J. Werbos, "Technological Solutions for Energy Security," *Energy Security Challenges for the 21st Century* edited by Gal Luft and Anna Korin (Santa Barbara: ABC CLIO, 2009) 286-288.
[74] Huber and Mills, 86-87.

generations to fully evolve so it is unlikely that a magic bullet solution will occur in the short-term.

Nuclear Renaissance?

There has been considerable discussion that nuclear power will undergo a significant renaissance around the globe as countries try to reduce harmful emissions created through electrical generation. Two dynamics are at play with regards to the nuclear industry globally. The first is that there will be a need to replace existing capacity as the plants that lead the growth in the industry in the 1960s and 1970s come to the end of their life cycles. These older plants will no longer be able to operate so their generation will have to be replaced either by rebuilding the existing plants, by constructing new ones, or exploring other options.[75] The second dynamic is the desire by current non-nuclear power states to acquire their own nuclear power generation capacity. In recent years more than sixty countries, most from the developing world, have informed the International Atomic Energy Agency (IAEA) that they intend to launch nuclear power programs in the near future.[76] How many of these developments transpire remains to be seen.

One of the major impediments to a significant growth in nuclear power generation is the very long time for approvals, construction, inspection and connection to the grid in many countries. Construction costs are also quite high and typically they tend to cost much more than initially estimated.[77] The recent global economic crisis has many countries observing more austere fiscal policies than previously so some of the states that had indicated a desire to move forward may delay or cancel these plans.

In addition to the issues of time and cost, there are other even more troubling concerns. The first is the matter of spent fuel rod disposal. These rods pose a risk to the environment if not contained properly and also provide a potential source for the development of nuclear weapons or dirty bombs by countries or terrorist groups.[78] Another concern is the deliberate use of a nuclear energy program to

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[75] Smil, *Energy at the Crossroads*. 311.
[76] International Atomic Energy Agency, *IAEA Annual Report 2009*. 1-2. Accessed on 18 April 2011 at http://www.iaea.org/Publications/Reports/Anrep2009/anrep2009_full.pdf.
[77] Grunwald, 132.
[78] David J. Rothkopf, "Is a Green World a Safer World?" *Foreign Policy* 174 (September/October 2009) 135-136.

develop a weapons program. The ongoing international unease regarding Iran's intention is a case in point. Development of a nuclear weapons program can occur when nuclear power states possess their own enrichment facilities or reprocessing plants. While there are international safeguards in place under the auspices of the IAEA to monitor existing plants, states can decide to abrogate their responsibilities, expel inspectors and do as they wish. Alternatively, they could choose to develop a covert programme and attempt to hide it from inspectors.[79] Proliferation of nuclear technology clearly poses a potential threat to global security through the weaponization of nuclear fissile material or the use of spent radioactive fuel.

Another worry is the potential risk from accidents at plants. This problem increases public concerns regarding the safety of nuclear power and has had an unfortunately periodic recurrence including the Three Mile Island accident in the U.S. in 1979, the disaster at Chernobyl in Ukraine in 1986, and the ongoing crisis at the Fukushima nuclear generator in Japan. Events such as these fuel perceptions that nuclear energy is not safe and garners resistance to new construction in some markets as evidenced by recent protests in various places in the world.[80]

If the stated plans of many countries go ahead, the amount of electricity generated by nuclear plants will increase in the coming decades. Along with this growth, the risk posed by either deliberate weaponization of nuclear material or accidents will increase and pose heightened security challenges in the future.

Infrastructure

A major determinant in the security and reliability of energy supply, particularly oil and gas, is the network of pipelines, shipping facilities, and shipping chokepoints through which oil and gas must travel to transit from producer to consumer. Interruptions to any of the critical nodes can have a significant negative impact on global energy security and contribute to price spikes when markets are inadequately supplied. Similarly, the bulk of electricity consumed in the world travels along a network of transmission lines that are linked with

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[79] Charles D. Ferguson, "A Nuclear Renaissance?" *Energy Security Challenges for the 21st Century* edited by Gal Luft and Anna Korin (Santa Barbara: ABC CLIO, 2009) 295-299. See also Eduardo González and José Martínez-Val, "Nuclear Energy: World Perspectives," *Energy Security* edited by Antonio Marquina (London: Palgrave MacMillan, 2008) 232-243.
[80] "Anti-nuclear protests in Germany and France," *BBC News*. (25 April 2011).

generation facilities, transformers, and sub-stations that distribute the stepped-down voltage to consumers. There are several key global chokepoints for oil and natural gas that will be highlighted in this section.

In 2009 the world consumed approximately 84 mbpd of oil and 2940.4 billion cubic metres (bcm) of gas.[81] Roughly 200.9 bcm,[82] or 6.8%, of the gas was LNG. All of the LNG and much of this oil were transported by sea to its consumers. While some of the ships voyaged directly across oceans or seas from their point of origin to their destination, a significant portion had to pass through one of seven shipping chokepoints around the world. These nodes include the Strait of Hormuz, the Strait of Malacca, the Suez Canal, Bab el-Mandab, the Bosporus Straits, the Panama Canal, and the Danish Straits. In 2009, 15.5 mbpd of oil or refined products flowed through the Strait of Hormuz, 13.6 mb/d passed through the Strait of Malacca, 1.8 mbpd passed through the Suez Canal, 3.2 mbpd passed through Bab el-Mandab, 2.9 mbpd shipped through the Bosporus Straits, 0.8 mbpd passed through the Panama Canal, and 3.3 mpd transited the Danish Straits.[83] It is important to remember that the flow of oil and LNG in 2009 was down from the amounts recorded prior to the global economic crisis. As consumption rises in the coming years, the amount of oil products and LNG flowing through these chokepoints will increase as well.

The Cost of Doing Business

While it is clear that there several options being developed and there is still room for growth for fossil fuels, it is also clear that global energy demand will continue to rise and that will lead to an increase in the cost of virtually all aspects of our lives. Another fact is that consumption of fossil fuels at higher rates will add to the production of CO_2 and other by-products that are harmful to the environment. As Nobuo Tanaka, the Executive Director of the International Energy Agency recently indicated, the degree to which costs will rise and the environment will suffer depends significantly on the investment choices that companies and countries make today. Significant investment is required in the traditional energy infrastructure, including nuclear power, as well as in

[81] *BP Statistical Review of World Energy 2010.* (June 2010) 11 and 27.
[82] *BP Statistical Review of World Energy 2010.*(June 2010) 31. I was unable to find any precise figures on the amounts of LNG shipped through each of the chokepoints but I assume that a large percentage of the total did pass through at least one of these points.
[83] Energy Information Administration, *World Energy Chokepoints*. (February 2011). Accessed on 26 April 2011 at http://www.eia.doe.gov/cabs/World_Oil_Transit_Chokepoints/Full.html.

alternative sources of energy supply.[84] Rising energy costs will impinge upon the ability of all states to sustain economic growth and will increase the operating costs of their governments and military forces.

4. Contemporary Threats to Energy Supply

In the preceding parts of this analysis, the lessons from previous energy transformations as well as the contemporary and future state of the energy environment were examined in order to situate the conditions in which threats to energy supply exist. It is important to understand these points to better appreciate how potential threats to energy supply might affect energy security currently and into the future. Energy supply reliability is a cause for concern for most states. While supplies often arrive without interruption, there have been several cases where disruptions, be they short- or long-term, have occurred and caused economic, social, and health problems. These interruptions can be attributed to malicious intent on the part of state or non-state actors, human error leading to accidents, or extreme weather and natural disasters. Amongst the potential threats nationalization of infrastructure, politically motivated disruptions, terrorism/insurgencies, piracy, inter-state conflicts, major industrial or transportation accidents, and natural disasters have all negatively affected global energy supply security in recent years. It is likely that they will continue to do so into the future. These threats will be examined in this portion of the paper.

Nationalization

Nationalization of energy industry infrastructure refers to the practice by some countries of taking over the operations of international oil companies (IOCs) — either by purchasing IOCs at fair market value or by other less equitable methods — or exploiting previously undeveloped resources through a state-owned oil company. In theory, the impact of nationalization on global energy markets could be null since the newly nationalized entity could continue to develop and market the product with the same efficiency of a non-state company. Indeed, there are examples of nationalized companies (NOCs) that operate in much the same way as private companies. Norway's Statoil is a well-known and efficient

[84] IEA Press Release. *The age of cheap energy is over, IEA Executive Director warns*. 21 April 2011. Accessed on 25 April 2011at http://www.iea.org/index_info.asp?id=1928.

example. However, in practice nationalization often has a negative impact on security of energy supply.

The ratio of NOCs to IOCs has changed dramatically since the 1970s such that as of 2008 approximately 92% of total global reserves are held by nationalized companies and they accounted for 81.5% of total global oil production.[85] Clearly NOCs dominate contemporary oil markets and this is unlikely to change in the near-term given the tendency in countries such as Venezuela and Ecuador to nationalize more operations in recent years.

This market domination can lead to supply shortages for several reasons. One is the relative inefficiency of NOCs compared to IOCs. In short, many NOCs do not operate as well as IOCs thus they leave more resource in the ground as compared to IOCs. This reduces the amount of oil available for the market.[86]

A related problem is the rapacious diversion of revenue from oil and gas operations to government coffers. Often NOCs belong to countries that lack functioning taxation systems so they strip their companies of money to pay for other, often non-productive, programs. These programs themselves can be destabilizing in that NOC revenues sometimes sustain arms races or support terrorists or insurgencies. Regardless of the end-use, the misdirection of revenue dramatically reduces the amount of money that is needed to reinvest in the NOC's operations leading to production declines and, potentially, global market shortages.[87] Venezuela and Mexico are notorious for their use of NOC revenue in other sectors leading to a deterioration of their reserve productivity. During periods of low demand, this relative inefficiency and under-investment is less problematic. However, as demand goes up and the margin between supply and demand diminishes, NOC control of production exacerbates the supply problem.

Government management, often mismanagement, of revenue derived from nationalized operations can also lead to domestic security challenges. One

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[85] Peter Johnston, "The Security Impact of Oil Nationalization: Alternate Futures Scenarios," *Journal of Strategic Security* III:4 (Winter 2010) 4.

86 Stacy L. Eller, Peter Hartley, and Kenneth B. Medlock III, "Empirical Evidence on the Operational Efficiency of National Oil Companies," The James A. Baker III Institute for Public Policy and Japan Petroleum Energy Center Policy Report. (March 2007), available at:
http://www.rice.eduienergv/publications/docs/NOCs/Papers/NOC Empirical.pdf. See also: Robert Pirog, "The Role of National Oil Companies in the International Oil Market," *CRS Report for Congress.* RL34137, (August 21, 2007): 10.

[87] "The Changing Role of National Oil Companies in International Energy Markets," *Baker Institute Policy Report.* 35 (March 2007): 2.

obvious way this can happen is through the resource curse. Some of the nationalizing governments, satisfied that their own revenue requirements are met through the NOC, often fail to create the incentives and conditions necessary for the development of a thriving economy.[88] Another negative tendency is the development of a culture of corruption that is often evident in countries that depend on NOCs. Under these conditions many citizens have little or no opportunity to improve their lives and eventually may turn to political violence in order to force change.[89] Unrest in major oil and gas producing countries can lead to supply disruptions and price spikes that ripple through the international community.

The Energy Weapon

A more fundamental problem that stems from nationalization of oil and gas operations is the ability it provides governments to disrupt energy supplies for purely political objectives — the so-called `Energy Weapon'. Supply disruption of this type can be carried out by the producing states or by the transit states that control pipelines or transportation corridors. Their intent in doing so is to force a consumer state, or group of consumer states, to change their behaviour in a way that the antagonist desires. There have been many examples of this behaviour throughout the oil age and they have affected most shipment methods, although disruption via pipelines is perhaps the most recurring type. Russia has been accused several times in recent years of interrupting supply in this manner. For example, on the day that the Czech Republic agreed to accept a U.S. radar installation on its territory as part of the European Ballistic Missile Defense, Russia shut-down the pipeline through which it exported oil to the Czech Republic. The Kremlin claimed this was merely routine although unannounced maintenance; however outside of Russia many interpreted it as punishment for the Missile Defence decision.[90] Russia has also cut gas supply to Europe twice in recent winters, January 2006 and January 2009, ostensibly over pricing disputes with Ukraine however many observers interpreted these incidents to also have

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[88] Christine Ebrahim-zadeh, "Back to Basics - Dutch Disease: Too much wealth managed unwisely," *Finance and Development.* 40, No. 1, (March 2003).

[89] Indra de Soysa, "The Resource Curse: Are Civil Wars Driven by Rapacity or Paucity?" *Greed and Grievance: Economic Agendas in Civil Wars*, ed. Mats Berdal and David M. Malone (London: Lynne Rienner Publishers, 2000), 113-135.

[90] "Czech Republic: Russia's Revenge," *Stratfor*. July 14, 2008. Also see Andrew Kramer, "Czechs See Oil Flow Fall and Suspect Russian Ire on Missile System," *The New York Times*. July 12, 2008, and Judy Dempsey, "Russia further cuts its oil deliveries to Czech Republic," *International Herald Tribune*. July 30, 2008.

political rather than business motivations. These are just some recent examples of countries using their energy exports to influence the behaviour of consumer states.

These disruptions have their greatest impact when supplies of the resource in question are either low, or due to reliance on pipeline networks, not readily supplied by other sources. Assuming that global demand for oil and gas will rise in the future as anticipated; it is possible that states that have nationalized these resources may make use of the energy weapon more often in the future. Although, they too can suffer as a result since these countries are often heavily reliant on their resource exports since they often do not have many other viable revenue sources.

Terrorism

Global terrorism aimed at oil extraction or transportation facilities is another serious threat to energy security and will likely continue to be one. The energy industry is a rich target environment for terrorists. Vulnerabilities include pipelines, refining and storage facilities, shipping chokepoints, and loading facilities. Given the integrated nature of many energy markets, this infrastructure crosses international borders and other political jurisdictions further complicating protective measures. Pipelines are perhaps the easiest targets to hit given their length and thus exposure in areas difficult to monitor. However, pipelines are relatively easy to fix or reroute, and, therefore, an attack at a concentrated high value target, such as a major refinery or a significant oil transit chokepoint, would yield a much higher return for terrorists.

There are many examples of this activity throughout the world in recent years. Some of these attacks are localized and related to regional conflicts such as the ongoing insurgency by FARC in Columbia where pipelines and electrical assets are attacked frequently. There are also attacks that are international in origin, specifically those orchestrated by al Qaeda[91] in its effort to cause economic havoc in order to push the U.S. and the West out of what it considers the Muslim world.

[91] For a more detailed examination of the threat posed by al Qaeda to the oil and gas industry see: Peter Johnston, *Oil and Terrorism: al Qaeda's Threat* DRDC CORA TM 2008-12 (April 2008) accessible at: http://cradpdf.drdc-rddc.gc.ca/PDFS/unc87/p529749.pdf.

As early as 1996, al Qaeda leader Osama bin Laden declared his desire to destroy the economies of the United States and other Western countries as a tactic to force them to leave the Middle East. Initially, bin Laden advocated only attacks on Western employees of the industry within the Middle East.[92] However, in 2004, the list of acceptable targets was expanded to include infrastructure in the Persian Gulf region. Al Qaeda and sympathetic terrorist groups inspired by it have carried out attacks on oil industry personnel, infrastructure, and shipping in the region periodically since that time.[93] In 2007, al Qaeda again broadened the target list to include all infrastructures that supplies oil and gas to the United States, including elements located in Canada, Mexico, and Venezuela.[94]

To date, these attacks have periodically reduced the amount of crude available to the markets slightly but have not yet brought down Western economies. There has been some economic impact in the form of the so-called terror premium that is estimated to add between $2 and $10 USD to the price of an oil of barrel.[95] Moreover, al Qaeda, despite several attempts, has not been successful in destroying or crippling a major facility in Saudi Arabia such as the Abqaiq refinery. However, it is important to remember that al Qaeda has demonstrated a capacity to correct mistakes and repeat successes from previous operations. This was perhaps best evidenced in its development of a maritime attack capability. On October 6, 2002, a French oil tanker was crippled by suicide bombers off the coast of Yemen in an attack that mirrored the suicide bombing of the USS Cole in Aden on October 12, 2000.[96] Based on its demonstrated ability to incorporate lessons learned, it seems likely that the organization, or those inspired by it, will improve upon previous efforts to attack oil and gas infrastructure, with potentially devastating effect on the global economy.

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[92] Daveed Gartenstein-Ross, "Al Qaeda's Oil Weapon," *The Weekly Standard*. October 3, 2005.
[93] Anthony Kimer, "Bin Laden and the Oil Weapon," *HS Today*. 23 October 2007. See also Fred Burton, "Attacks on Energy Infrastructure: Desire, Capability and Vulnerability," *Stratfor*. 2 March 2006.
[94] Ian MacLeod, "Al-Qa'ida targets Canada," *CanWest News Service*. 14 February 2007; and "Al-Qaeda calls for attacks on Canadian oil facilities," *CanWest News Service*. 23 October 2007. See also "Al-Qaeda calls for oil attacks," *Aljazeera.net*. 14 February 2007. See also Hameed Bakier, "Sawt al-Jihad Calls for Attacks on Western Energy Interests," *Terrorism Focus*. 4:2. 20 February 2007.
[95] Robert Block and Chip Cummins, "Saudi Arrests Stoke Oil Facility Worry," *Wall Street Journal*. 28 April 2007. See also John W. Schoen, "Oil prices include a growing _risk premium," *MSNBC News*. 12 May 2004. See also Scott Peterson, "Why oil prices may stay high," *Christian Science Monitor*. 2 August 2004.
[96] "French Tanker Explosion Confirmed as Terror Attack," International Policy Institute for Counter Terrorism. (October 10, 2002).

As oil and gas demand grows it is likely that there will be times when excess supply may not be available. It is during these periods when the potential impact of a terrorist attack on oil or gas infrastructure could be the most damaging in terms of its effect on the global economy. It seems very likely that this threat to fuel supplies will remain for the indefinite future at both the international and regional levels.

Piracy

Piracy is a problem for all ship-borne traffic in certain parts of the world. According to a 2011 report issued by the International Maritime Bureau's Piracy Reporting Center there has been a steady increase in reported piracy incidents worldwide in recent years. In 2010 there were a total of 445 incidents reported of which 217 occurred off the shores of Somalia either in the Gulf of Aden, the Red Sea, or the Indian Ocean and were attributed to Somali pirates. The numbers of reported incidents show a shift in the area Somali pirates target away from the Red Sea (25 incidents) and Gulf of Aden (53 Incidents), focussing more on the Indian Ocean (139 incidents) than previously was the case. This development suggests an improved capability for pirates in this area to operate further from shore and also a desire to avoid the naval task force operating against them in the Gulf of Aden. Other areas that stood out for higher numbers of attacks in 2010 were offshore Nigeria, Bangladesh, the South China Seas, offshore Vietnam, Malaysia, Indonesia, Peru, and Brazil. There were two reported incidents in the Malacca Strait and three in the Singapore Strait.[97] Overall, the report shows a steady year on year increase in acts of piracy in recent years. This suggests a trend toward more in the future.

Several of these reported incidents were directed against vessels associated with the petroleum industry. The paper notes that the reported incidents involved 63 chemical tankers, 43 crude tankers, 33 product tankers, 7 liquid petroleum gas tankers, 2 bitumen tankers, and 1 LNG tanker.[98] These attacks can cause disruption to the supply chain particularly in light of the size of some of the tankers; some mega tankers are capable of carrying 2 million barrels of product. The loss of the product from the market, even if only temporarily, can lead to price spikes and possibly shortages in some areas. Moreover, the costs incurred

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[97] ICC International Maritime Bureau, *Piracy and Armed Robbery Against Ships Annual Report 1 January – 31 December 2010*. (January 2011) 5-6.
[98] Ibid. 14.

by companies to free their vessels, crews, and cargoes — tankers are a very lucrative target for the pirates[99] — must ultimately be passed on to the consumers either directly for sale of the product of indirectly through rising insurance costs.

Conflict and Instability

Conflict and instability can have a negative impact on the availability of fuel and energy supplies. This impact can occur due to conflict in the producing or transit countries that lead to disruption of the extraction, refinement, or transportation of the resource. There have been many examples of this type of conflict leading to reduced availability of products on the open market.

Over 56.6% of the world's proved oil reserves in 2009 were located in the Middle East. Venezuela possessed roughly 12.9% while Russia had 5.6% and Kazakhstan held 3%. Africa held 9.6% of which 3.3% were located in Libya and 2.8% in Nigeria. Asia Pacific only possessed 3.2% of the proved reserves in 2009.[100] Turning to proved gas reserves in 2009 and the situation is similar with 40.6% being found in the Middle East, 23.7% in Russia, and the rest spread out throughout the world.[101] Clearly, the bulk of the world's oil and gas are located in regions or countries that can be characterized as unstable or prone to manipulating exports to meet their political objectives. The Middle East in particular is the scene of unrest in many places in recent months. The collapse of any of the world's major oil suppliers could disrupt global supply and possibly trigger an intense competition for oil amongst dependent states.

An obvious example of conflict and turmoil resulting in reduced global energy supply is evident by reviewing production totals in Iraq. Iraq's production had grown to a high of 3.489 mbpd in 1979 at the start of their conflict with Iran. It quickly dropped to 0.907 mbpd in 1981 and did not top 2 mbpd until 1987 then hitting a decade high of 2.838 mbpd in 1989. Iraq invaded Kuwait in August of 1990 in an effort to seize Kuwait's oil reserves and almost immediately its production again began to drop so that its 1990 total was 2.149 mbpd. Worse was to come for Iraq due to the first Gulf War and the sanctions that followed, production was well below the 1989 level, failing to top 1 mbpd until 1997 and

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[99] Abdi Guled and Abdi Shei, "Somali pirates haul in record ransom for oil tanker," *Financial Post*. 18 January 2010.
[100] *BP Statistical Review of World Energy2010* (June 2010) 6.
[101] *BP Statistical Review of World Energy 2010* (June 2010) 22.

rising to 2.523 mbpd in 2001. In 2003, the year of the second Gulf War, production dropped to 1.344 mbpd and hovered around the 2mb/d mark until 2009 when it had a recent peak at 2.482 mbpd.[102] This record of production peaks and valleys shows a clear link between conflict and reduced production in Iraq – arguably, more than 1 mbpd of potential production is not available to the global market due to the fighting that has gone on in Iraq. There are many other countries where similar production trends can be observed such as Nigeria and Columbia where attacks on oil and gas infrastructure by insurgents, disgruntled populations, or criminal gangs stealing resources are a fairly regular occurrence. These incidents result in production losses in these countries and, in combination, reduce the amount of product available on the markets.

The Russian invasion of Georgia in August 2008 was cited by many observers as a direct attack on oil supplies destined for Western markets — the Baku-Tblisi-Ceyhan (BTC) and the Baku-Supsa pipelines both transport Caspian basin oil to Europe — rather than the stated intent of protecting Russians in the break-away sections of the country. There were other reasons that Russia may have invaded as well. Particularly Georgia's growing cooperation with NATO and the West that was viewed negatively by Russian leaders so the invasion would send a message to Georgia and to Western leaders that Georgia was still part of Russia's backyard. Any of these reasons are plausible and there were disruptions to the oil supply during the period of the conflict. Interestingly, these interruptions were not the result of direct attacks on the pipelines by the Russians. A section of the BTC in Turkey had been shut down two days before the Georgian conflict due to a fire, allegedly started by PKK rebels. The Baku-Supsa line was shut down by its operator, BP, as a precautionary measure to avoid any losses if there was damage from the conflict. However, neither of these pipelines was attacked by the Russian forces during this period.[103] While the true Russian motivation may never be known or accepted by all, the invasion did project a clear message that should it choose to do so, Russia could interrupt these vital pipeline routes and disrupt supply from the Caspian to Europe.

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[102] All production data for this section come from *BP Statistical Review of World Energy 2010 – Historical data* (June 2010). Accessed on 28 April 2011 at:
http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2010_downloads/Statistical_Review_of_World_Energy_2010.xls#'Oil Production – barrels'!A1

[103] Tracey C. German, "Pipeline politics: Georgia and energy security," *Small Wars and Insurgencies*. 20:2 (June 2009) 344-362.

Another contemporary example of conflict having a negative impact on fuel supply is occurring in Afghanistan. Due to the land-locked nature of Afghanistan and the isolation of the bases that support it from direct oil or gas production areas, virtually all of the fuel, gas, heating oil, and lubricants consumed in the country must be shipped into the theatre of operations. ISAF forces in Afghanistan are generally supplied through Pakistan. Given the unstable nature of the Pakistani territory that these fuel convoys must pass through, they are often targeted by enemy combatants. These challenges increase the costs of supplying Afghanistan such that the fully burdened cost of fuel, that is the price factoring in all of the logistical and security support needed to get it to the end-user, has been reported as high as $400 USD per gallon.[104] This particular figure may be open to debate depending on the model used to derive it, but the fact is that supplying military forces in war zones with energy resources is extremely costly and this cost is likely to rise as the market prices rise. Operations such as those being conducted in Afghanistan are incredibly energy intensive so the burden that this high price for fuel places on the countries that are participating in the war in Afghanistan is extremely high and difficult to quantify.

Accidents, Labour Unrest, and Natural Disasters

While these events are not attributable to hostile intent, they need to be considered and, to the extent reasonable, measures should be enacted to provide energy security when events such as this cause supply disruptions. When they do occur, events such as these can lead to energy supply disruptions.

Industrial accidents or labour disputes involving production or transmission units of energy chains do occur and can cause significant short-term and even long-term supply disruptions. An example of both occurring at the same time demonstrates the challenges these types of events can create. In February 2007 a fire at an Imperial oil refinery in Nanticoke, Canada, lead to a major shortage of refined product for gas stations in parts of the province of Ontario. Normally, it would have been possible to move in supply from Canada's east coast by rail to offset the losses. However, rail workers happened to be on strike at that time so the result was the closure of some gas stations and inadequate supply in some

[104] Roxana Tiron, "$400 per gallon gas to drive debate over cost of war in Afghanistan," *The Hill*. 15 October 2009. Accessed on 28 April 2011 at http://thehill.com/homenews/administration/63407-400gallon-gas-another-cost-of-war-in-afghanistan-.

parts of the province for many days.[105] While it may be rare to have both of these events occurring at the same time, it is clear that accidents and labour unrest can lead to supply shortages and may necessitate seeking supply from alternative sources.

As noted above, ships carrying oil and LNG may have to pass through one or more chokepoints on their way to market. Given that these ships can carry upwards of 2 million barrels of oil or product, disruptions to these chokepoints could result in significant supply shortages on global markets until they can be resolved. Some of the chokepoints are narrow enough that it is possible that a large tanker were to become disabled due to an accident and block one of these passages. This could have a disruptive affect on global fuel supply. An example of a major chokepoint blockage occurred in 1956 when Egypt nationalized the canal. At that time, nearly 10% of global crude oil trade transited through the canal.[106] The seizure and blockage of the canal led to the Suez Crisis and contributed to an already moribund global economy due to the fuel shortages it created in many markets. Blockages in oil and gas chokepoints in the future could have devastating effect on global energy markets and, consequently, on the global economy.

Natural disasters such as earthquakes or severe weather events can also lead to energy supply disruptions. There have been many examples of these events in recent years including Hurricanes Ivan (2004), Rita (2005), Katrina (2005), and Ike (2008) that ripped through the Gulf of Mexico damaging and destroying significant oil and gas facilities located in and around the region. These events created major fuel supply challenges in the U.S. and necessitated the acquisition of supply through the sharing mechanism of the IEA. The devastating earthquake and tsunami that struck Japan in March of this year provides another tragic example of the disruption to energy supply, primarily electricity in this case, that can result from catastrophic natural disasters.

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[105] "Refinery fire leaves some Ontario gas stations short of fuel," *CBCNews*. 20 February 2007. Accessed on 28 April 2011 at: http://www.cbc.ca/news/canada/toronto/story/2007/02/20/imperial-shortages.html.
[106] International Energy Agency, *Facts on Egypt: Oil and Gas*. 3 February 2011. Accessed on 28 April 2011 at: http://www.iea.org/files/facts_egypt.pdf.

5. Conclusions

General

It is clear that with growing population and economic development global energy consumption will continue to rise for the foreseeable future. The challenge that the world faces is that the bulk of the existing primary sources of energy, namely oil, gas, and coal, are fossil fuels and are finite in their amount. Eventually they will be depleted to the point where continued consumption will no longer be economically viable. Additionally, the consumption of these fossil fuel resources has had an environmentally detrimental consequence on the world and continued high consumption of these resources will worsen this.

An energy transformation is occurring in response to these facts. It might extend the useful life of the fuel sources society depends upon and also facilitate the development of other resources or technologies that will permit the continuation of activities that are fuelled or powered by fossil fuels.

While some observers suggest that this transition must occur quickly, history provides examples of previous energy transformations and it seems likely that the process will be generational in duration. Currently, one aspect of the transformation is the replacement of oil by gas for some uses. While this is a fossil fuel for a fossil fuel change, gas burns more cleanly reducing negative environmental impacts and it is more abundant than oil— particularly as technology improves permitting the commercialization of shale gas, tight gas, coal-bed methane, and possibly gas hydrates in the future.

In addition to the shift to gas, there are a significant number of other developments taking place that will move the transformation along. The world has witnessed a growth in electrical generation capacity powered by wind and solar energy amongst other alternates in recent years. At the same time, demand growth is high enough in some markets that coal powered plants will continue to be built and likely drive up coal consumption rates in the future. It is also possible that the world might undergo a nuclear renaissance and increase the amount of electricity generated in these plants. Although, it seems that there are limits, not least of which are cost and security concerns that may limit the amount of new nuclear power capacity.

Over time there will be options, once perceived to offer great potential, which will be found to be untenable. Naturally the effectiveness of the new energy

choices will influence the selections. Another issue for these alternatives is scale, that is can they be produced and distributed widely enough for practical use. Along with scale, affordability will influence the eventual selections as the cheaper forms of energy will make more sense economically — hence the addiction to oil that characterizes contemporary society. New infrastructure will be required to carry the energy sources to market. The existing oil, gas, and electrical infrastructure have evolved over a century and the costs were incremental on that scale. Any new infrastructure will likely also be developed slowly in order to make the costs sustainable and to lessen the risk that a given choice does not work out as hoped.

A final consideration, albeit not the least, for potential transformational choices is their impact on the environment. This has been a crucial shortfall of fossil fuels so the environmental sustainability of new sources of energy should have some influence upon the choices made.

Implications for Countries

The energy transformation currently underway provides both opportunity and challenge for countries. Without focussing specifically on any one country, it is difficult to offer more than general observations on these potential risks and rewards.

One obvious opportunity is the potential for economic growth provided that countries guide their energy developments on paths that prove to be effective. This is the challenge as there will be many options open in the future but many of them will prove to be fruitless paths. It may be that bio-fuels will one day be considered to be a failed option in light of the growing understanding of their negative consequences. Of course, there is the potential for failure on the part of many countries. As noted above, some countries are already woefully behind the developed world in terms of their access to energy resources. This is a considerable contributor to unrest and conflict in some parts of the world as people lack the basic energy they require to carry out daily functions such as cooking and heating, let alone get involved in productive economic pursuits. This situation could grow more severe as energy costs rise with demand.

Given that industry has been at the forefront of previous energy transformations, it will likely continue to occupy that post. Businesses that tap into the changes presented by the ongoing transformation will likewise have an opportunity to flourish or perish depending on the choices that they make.

Governments also have a role to play in this evolution. One responsibility is to regulate appropriate guidelines for these developments — particularly as regards trade, industry, and environment — to ensure that they occur within the auspices of relevant trade agreements, that they are safe, and that they are developed in an environmentally sustainable manner. Government might also encourage some developments through tax breaks or consumer incentive programs. At the same time, undesirable choices might be limited by the imposition of taxes or legislation as appropriate. Governments can also provide funding for research and development to move this transformation along. These incentives, disincentives, and funding must be undertaken in accordance with any agreements or treaties that the countries are party to. Moreover, they must be done with careful weighing of expert advice as the governments may not be the best suited to decide if a given option is viable or destined for failure.

Another crucial impact for governments will be the impact that the energy situation has on their revenue streams. Countries that rely heavily on oil and gas exports to generate GDP will likely prosper in the coming decades if the forecasts for continued high prices prove correct. However, this may simply exacerbate existing economic distortions and not necessarily improve the overall economic picture in some countries. These revenue streams might also fuel more instability as some states, not particularly accountable to their populations could use the money to fund destabilizing arms programs or terrorist groups.

There are also strategic opportunities and risks that will result for countries as the energy transformation unfolds. Dependencies will potentially change as a result of the manner in which energy developments occur. Indeed, it seems that there is already short-term potential for some countries to reduce their dependency on imported gas by developing the shale gas, coal-bed methane, or tight gas deposits that have sat unutilized for these past decades. Eliminating these dependencies reduces the pressure that some producer states have exerted by interrupting or threatening to interrupt supply. Similarly, developing or increasing strategic reserves of strategic energy supplies will lessen the impact of any supply disruptions for states. Also, a move to greater energy cooperation between countries could reduce the negative impact of disruptions. While some analysts advocate increasing energy independence as a means to increase energy security, it may be more logical to increase energy cooperation with allies and like-minded countries.

Over the long-term, there is some potential for a significant reordering of the strategic map of the world. Areas that are important today because of their

supplies of oil or gas might become less relevant from a strategic perspective when the world reduces its consumption of these resources. It is also possible that some of the countries once strategically important for oil or gas might become important for some other energy resource or technology depending on the path they choose.

Implications for Military Forces

It is imperative that force planners and strategic planners understand the potential implications of the energy environment and the ongoing transformation. Energy is essential to mission effectiveness; if deployed forces lack the necessary fuel and power resources to carry out their basic combat, surveillance, and logistic functions, failure will result. It is a stark and simple reality.

As noted above, militaries have influenced the development of previous energy transformations and they should continue to push industry to develop novel energy technologies to help them gain a competitive edge against their potential adversaries. At the same time, military planners should be aware of the power and energy technology that is already developed and study how it might be of use now or in the future.

Force planning decisions need to be informed by an understanding of the contemporary and possible future energy environment. Given the long life-cycles of major equipment acquisitions, planners need to have confidence that the power or fuel required by a new platform will be available in sufficient and affordable quantities throughout that time. Alternatively, systems that afford flexible fuel and power use might also make sense. There are already a number of alternative power options available on the open market and it is likely that there will be even more in the future. These options should be explored in order to provide power for established bases but also to provide options for deployments that might not have access to other local sources. Again, this is a risk and opportunity decision node as choices made today may perform to specification in the future or might suffer critical failure at a crucial moment and lead to mission failure and defeat.

Military forces should also be examining ways to increase the environmental sustainability of their energy choices. This is important both from a cost perspective but also from the impact military activities have on the environment. Alternative energy sources have the potential to reduce costs, vulnerabilities, and

environmental impact and can also provide power options in remote deployments isolated from access to a functioning grid.

Another issue for military forces is the need to examine standard operating procedures and reassess those that might have a negative energy impact on the force. In the past, there was little concern paid to consumption habits for some military forces but as supply tightens, costs rise, and environmental impacts become more relevant, altering operations to reduce their energy impact where it will not compromise overall effectiveness becomes imperative. The scope of the changes need not be excessive to realize benefit. Maximizing loads to reduce transport trips is one easy way to achieve this. Rationalizing the frequency and duration of patrols can also lower the energy impact without reducing mission effectiveness in some cases. These are just a few of the options that, if put into practice across a force, can have a dramatic impact on reducing energy consumption without reducing operational effectiveness.

Potential energy resource scarcity in the future could challenge militaries by increasing conflict in energy poor areas or amongst states competing for supplies. There have already been conflicts attributable to energy, Iraq's invasion of Kuwait in 1989 being a case in point, and it is possible that if countries are unable to manage their energy needs in the future, more conflicts could result over the competition for access to energy. It is not possible or responsible to predict an increase or decrease in conflicts whose proximate cause is energy. However, the possibility that this might occur in the future should be kept in mind for strategic planners and contingency planning should occur.

Clearly there are many energy related challenges that will face military forces in the future. As should be apparent there is a requirement for situational awareness at a strategic, operational and tactical level and for continued research and development of options, be they doctrinal, conceptual, or technical, to prepare to meet the energy challenges of tomorrow. Continued concept development and experimentation, simulation, modelling, operational analysis, and strategic analysis will help inform decision makers regarding the options that might help enhance the energy security of military forces presently and into the future.

6. List of Abbreviations

Bcm	Billion cubic metres
BTC	Baku-Tblisi-Ceyhan pipeline
Btoe	Billion tons of oil equivalent
CO_2	Carbon dioxide
EIA	Energy Information Agency (U.S.)
FARC	The Revolutionary Armed Forces of Columbia
GW(e)	Giga-watts (electric)
GDP	Gross Domestic Product
GHG	Green House Gas
GTL	Gas to liquid
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IOC	International Oil Company
ISAF	International Security Assistance Force
LNG	Liquefied Natural Gas
Mbpd	Million barrels per day
MW	Mega-watts
Mtoe	Million tonnes of oil equivalent
NOC	Nationalized Oil Company
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
Tcf	Trillion cubic feet
Tcm	Trillion cubic metres
USD	United States Dollars
USGS	United States Geological Survey

THE TECHNICAL COOPERATION PROGRAM

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